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SPECIAL PROBLEMS
IN
RADIO DESIGN.

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SPECIAL PROBLEMS IN RADIO DESIGN.

By

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The following is a summary of the alterations made to the transmitting equipment of the University of Alberta Radio Station by Dr.H.J.MacLeod, J.W.Porteous and W.E.Cornish since it was first installed in the fall of 1927.

Presented to the Committee on Graduate Studies, the University of Alberta as a partial requirement for the Degree of Master of Science.

UNIVERSITY OF ALBERTA.

ELECTRICAL ENGINEERING DEPARTMENT

EDMONTON ALBERTA

APRIL 6 th.1933.

Radio Broadcasting has made tremendous headway within the last decade, especially in the last five years; and therefore it is the purpose of this paper to outline the various stages through which the transmitting equipment of the university Radio Station has past since its erection in the fall of 1927. Owing to the demand by radio listeners for less interference between stations and the ever increasing quality of reproduction by radio receivers it was essential that the transmitting equipment of the University Station be kept more or less up to the modern standards set by other stations. Thus in the summer of 1930 Dr. MacLeod and the writer commenced alterations to the then existing equipment. Mr. Porteous in another paper is outlining the changes made during the past summer to the input equipment up to and including the modulating tubes, so this paper will deal principally with that part of the transmitter from the modulating tubes to the antenna. I have endeavoured to outline these changes in the order in which they were made.

Before dealing with the changes that were made I will describe briefly the transmitting equipment as it was when first installed.

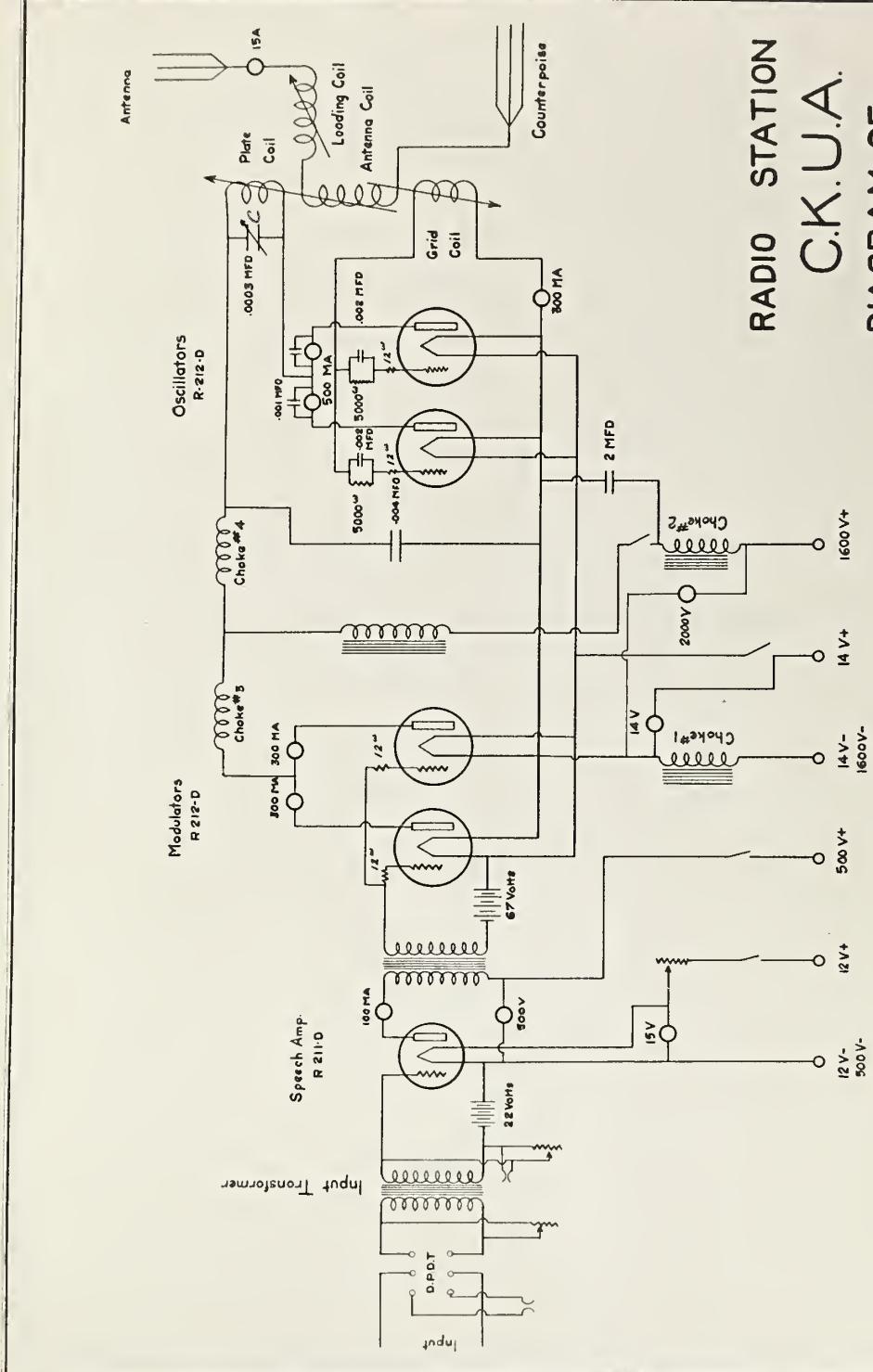
The transmitter was first installed during the fall of 1927 by W.W.Grant of Calgary and consisted of four-250 watt-R-212-D tubes and one 50 watt-R-211-D speech amplifier, together with the necessary coils, condensers, etc. Two of the 250-watt tubes operated in parallel as oscillators using a Meissner oscillating circuit. By the Heising system

modulation was obtained using the other two 250-watt tubes. The circuit of the original transmitter is shown in Fig. 1. Referring to the figure; at the extreme left is the input from the studio terminating in a D.P.D.T switch. This switch connects the studio line either to the listening jack or to the transmitter. Passing through the input transformer with volume control on both the primary and secondary we come to the speech amplifier tube. The filament supply for this tube comes from two six volt storage batteries in series, and the plate supply from 240 small storage batteries in series giving approximately 500 volts. The speech amplifier is coupled to the modulating tubes through a Ferranti audio transformer. The filament supply for the four 250-watt tubes is from the 14 volt direct current generator and the plate supply is from the 1600 volt generator. These four tubes draw their plate current through the large choke shown in the diagram producing modulation by the Heising system. This system will not be explained as Mr. Porteous is dealing with it in his paper. In both the filament and plate supply for these four tubes there are iron core choke coils, the purpose of these is to eliminate the small ripple in the current from the direct current machines caused by the commutators. The two oscillators, which are two 250-watt tubes, operate in parallel using a Meissner circuit. The plate coil, the antenna coil, and the grid coil are arranged so that there is coupling between the plate coil and the antenna coil and between the antenna coil and the grid coil. The antenna coil

NOVEMBER 1927

RADIO STATION
C.K.U.A.
DIAGRAM OF
CONNECTIONS

FIG. 1



is connected in series with a loading coil and the antenna and counterpoise, and by means of the loading coil this circuit is tuned to resonance for 580 kc. The plate coil and grid coil are both variable with respect to the antenna coil. The plate circuit of the oscillators is tuned by means of the variable condenser^C, the purpose of this is to control the load taken by the tubes according to their capacity.¹ In order for the radio frequency circuit to be complete there is a .004 mfd. condenser connected between the plate coil and the filaments. The R.F. Choke #4 prevents any radio frequency currents from passing back to the modulators. The 2 mfd. condenser connected between the filaments and the 1600 volt positive together with choke #2 is part of the filter for smoothing out the ripple in the high voltage supply. Grid bias for the oscillators is obtained by means of 5000 ohm resistances and .002 mfd. condensers. Grid bias for the other tubes is obtained by means of dry batteries.

HARMONICS.

Fig.2. shows the mutual characteristic curve for a vacuum tube. The mean operating voltage is marked and the grid voltage swings above and below this point. If the swing of the grid voltage is so great as to sweep over a non-linear portion of the curve during a cycle then harmonics will be introduced into the circuit.

1 Sterling Page 174.

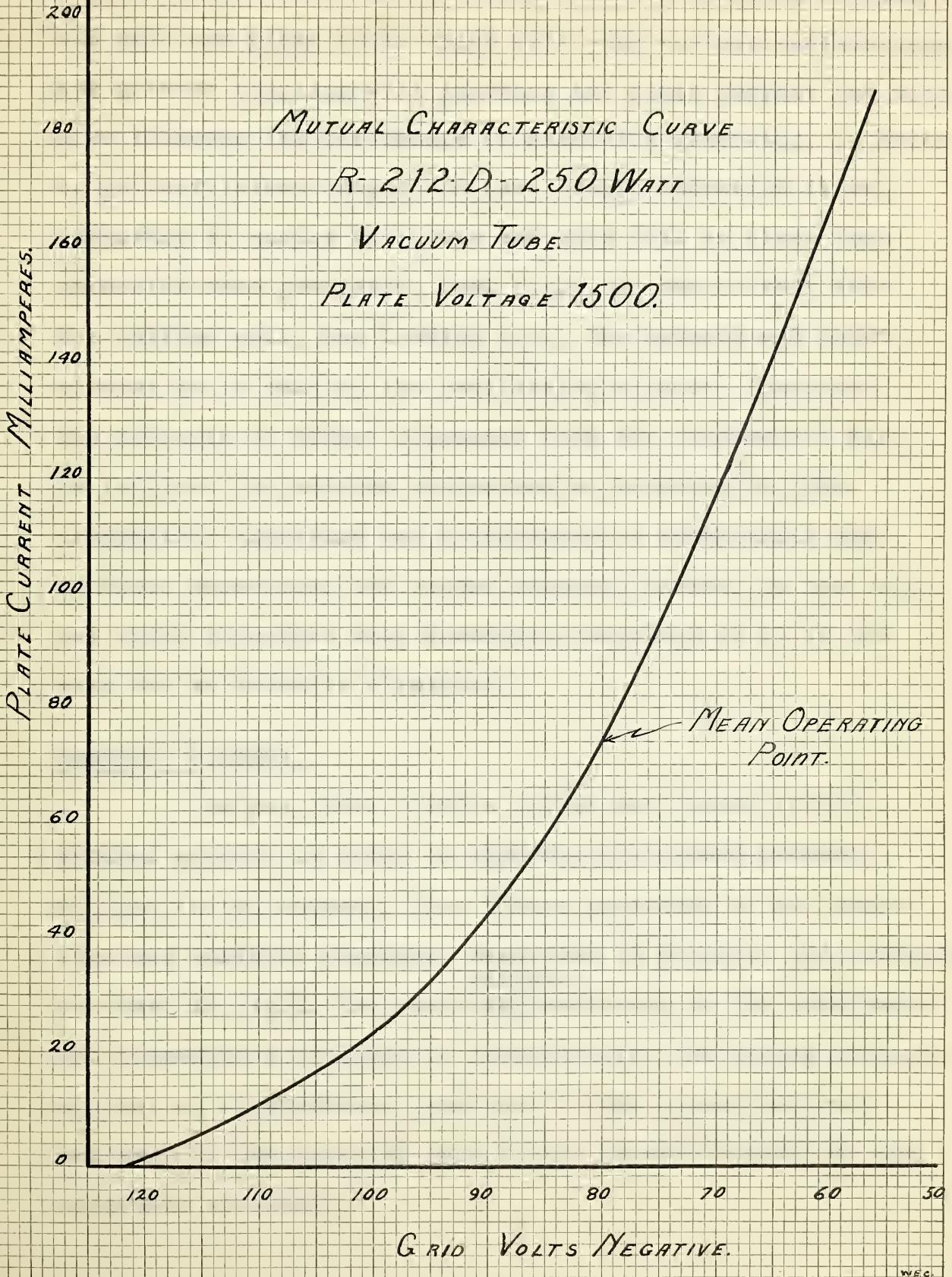


FIG 2.

In any oscillator if the operating potentials of the tube are fixed then there is a minimum value of coupling between the grid and plate coils which will just sustain oscillations. Any greater coupling will increase the plate current but will also increase the percentage of harmonics generated. In order to get sufficient output and have stable operation it was necessary to couple the plate and grid coil so close that harmonics were generated. From fig.1. it can be seen that the antenna coil, the loading coil, the antenna and counterpoise go to make up the oscillating circuit. Therefore any currents of higher frequency than the fundamental will be fed into the antenna system and be broadcasted. The transmitter therefore was broadcasting a fundamental and numerous harmonics; the second harmonic however is the only one which interferes with broadcast reception so it is the only one we tried to eliminate.

HARMONIC FILTERS.

On Dec. 10th. 1929 a filter was placed in the antenna circuit in order to suppress the second harmonic current in the antenna. This filter consisted of an inductance and variable condenser connected in parallel and connected circuit as shown in fig.3. The parallel consisting of the inductance and condenser were tuned to resonance for the second harmonic and act as considerable impedance to the second harmonic current. In constructing this filter we were limited to the apparatus available.

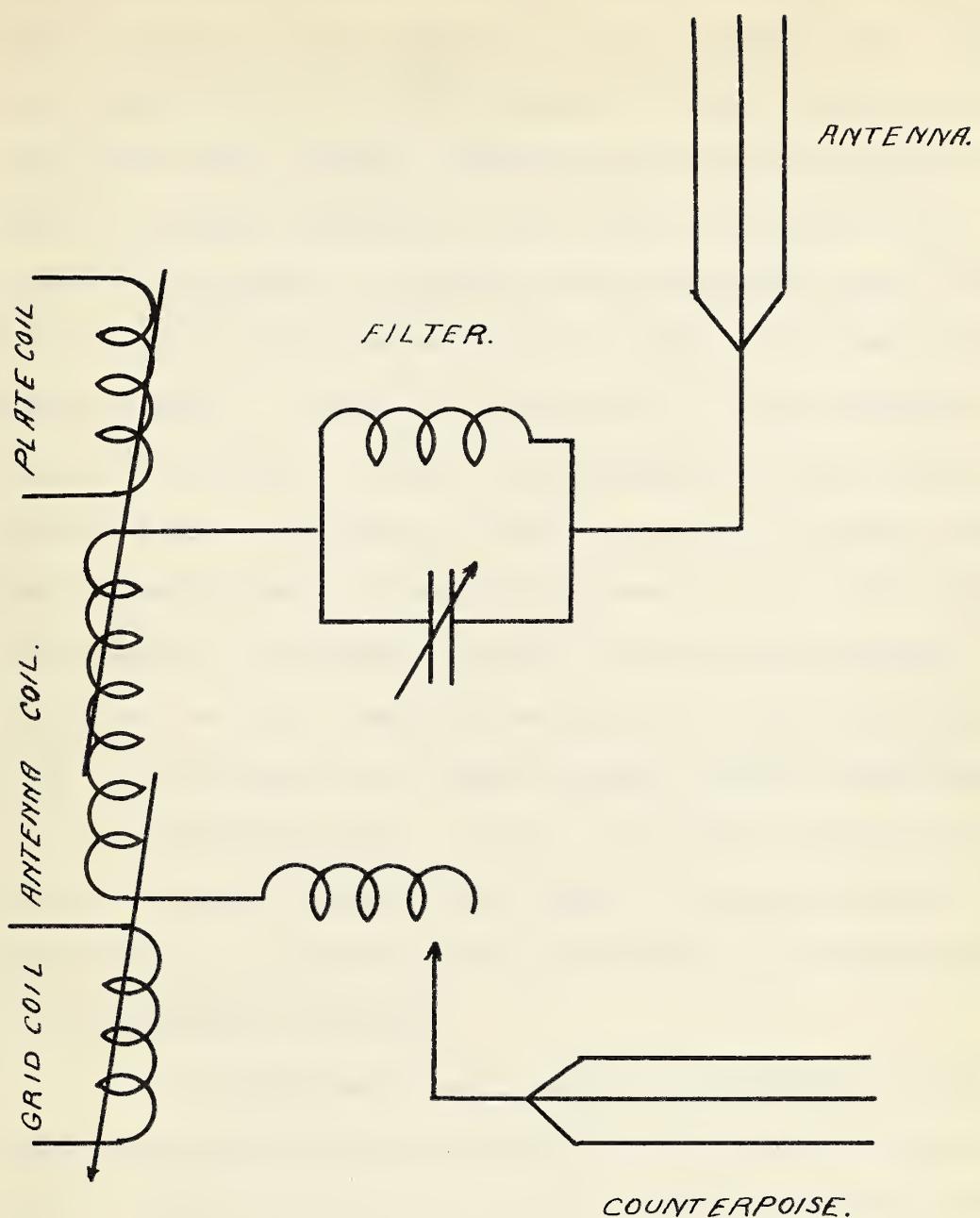


FIG 3.

The inductance consisted of 14 turns of copper strap the same as used in the antenna coil and loading coil. This had an inductance of 30 microhenrys. The only variable condenser available which would withstand the high voltage was a plate condenser immersed in oil. Half the plates were removed in order to increase the spacing and then a calibration curve was obtained for it. Using the formula that wave length --- $1884\sqrt{L.C.}$; the size of the condenser in order to tune this circuit to resonance for our second harmonic was calculated. To make sure that we were correct and to set it more accurately we used a local oscillator operating at a frequency equal to the second harmonic frequency and set the condenser accurately. The efficiency of the filter depends to a great extent on the resistance of the inductance coil. If this coil has a low resistance then the filter will be very sharp in tuning and when accurately tuned will be very effective in eliminating the second harmonic current.

Between Dec. 10th. 1929 and March 14th. 1930 numerous filters were tried both in the antenna circuit and in the plate circuit of the tubes. However on March 14th. 1930 a tank circuit was added as shown in figure 4. The condenser was built in the University machine shop at a considerable saving over any that could be purchased. The tank circuit was tuned by a variable inductance and the antenna tuned as before. Various methods were tried for

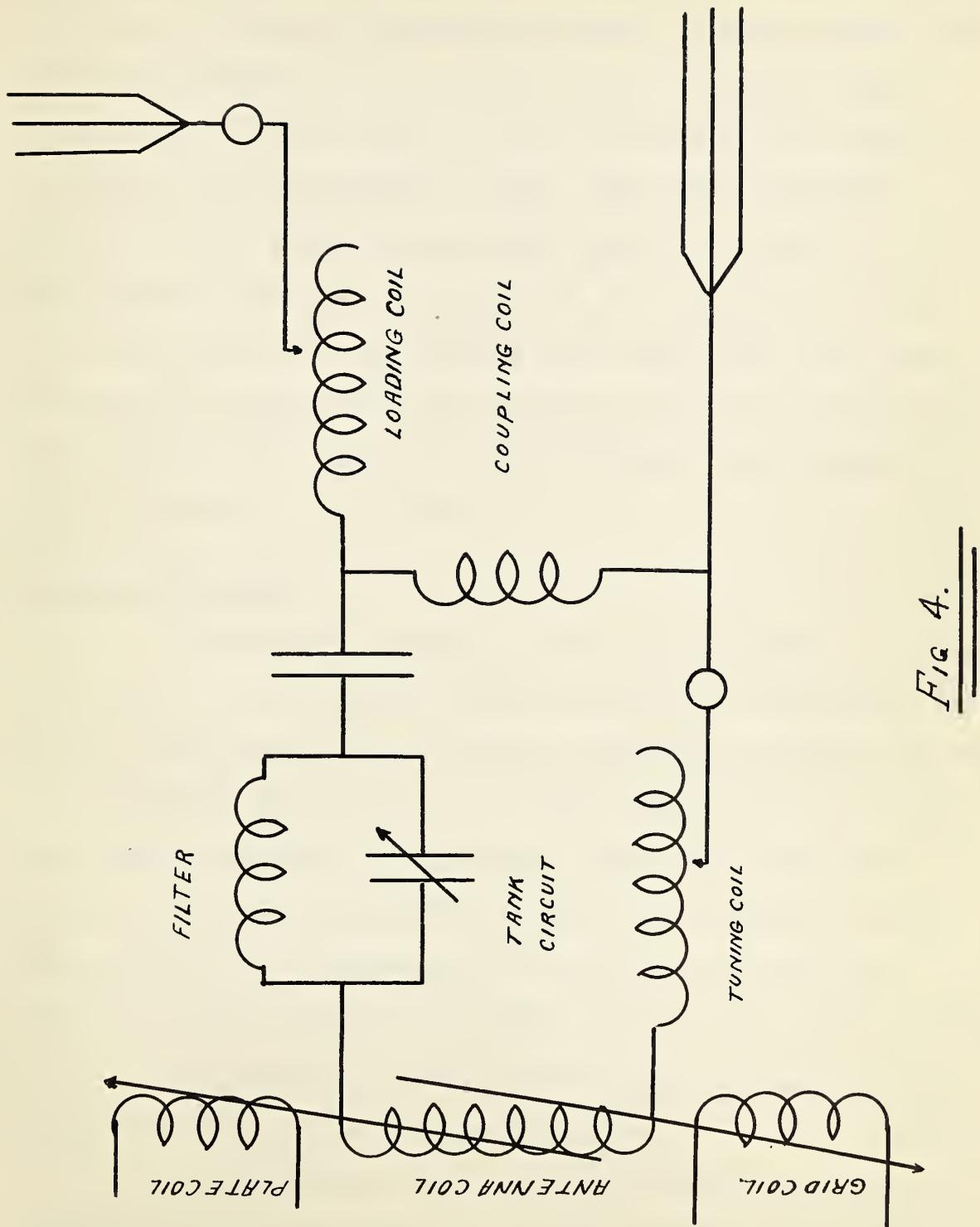


Fig 4.

coupling the antenna circuit to the tank circuit. At first capacity coupling was tried but it was found that these condensers would have to be very large and expensive in order to handle the high voltage and transfer the power to the antenna. The type of coupling finally used was direct coupling. This consists of a coil common to both the tank circuit and the antenna circuit as shown in fig. 4. The second harmonic filter was now placed in the tank circuit and very satisfactory results were obtained. The operation of the oscillator was more stable when the tank circuit was used because the inductance and capacity were more constant than the antenna inductance and capacity which varied by the swaying motion of the wires.

ANTENNA CONSTANTS.

During the summer of 1930 it was decided to increase the number of counterpoise wires used so as to increase the natural wavelength of the antenna-counterpoise system and to also increase the capacity. A counterpoise (which consists of a number of wires placed about eight feet above the ground, stretching between the towers and insulated from ground), has to be used with the University station on account of the fact that the knob on which the station stands is practically all sand. This would have too high an electrical resistance to use a ground system.

The frequency assigned to this station by the Federal Government is 580 kc. or 516.9 meters. With the original counterpoise of six wires the capacity of the

antenna system was .0004 mfd. and it required considerable loading coil to tune this circuit to resonance. This large loading coil constituted a source of loss, so by increasing the capacity we could cut down the size of the loading coil. By increasing the number of counterpoise wires to twelve and spreading them over a larger area the capacity of the antenna system was increased to .00052 mfd. Curves are shown illustrating how the capacity increased as the counterpoise wires were added.

Another advantage obtained by increasing the number of counterpoise wires was to increase the natural wave length of the antenna - counterpoise system from 228 meters to 246 meters. The advantage of this increase will be shown later.

After the counterpoise wires had been added measurements were taken in order to determine the antenna constants; namely the inductance, capacity, natural wavelength and the antenna resistance. Before describing the methods used to obtain these we will make a brief study of the antenna and antenna radiation.

Let us consider an antenna in its simplest form, namely, a long vertical wire connected to an alternator as shown in figure 5. This wire has:

- (1) Distributed inductance.
- (2) " capacity.
- (3) " resistance.

(1) The distributed inductance is due to the ability of every part of the antenna to develop magnetic lines of

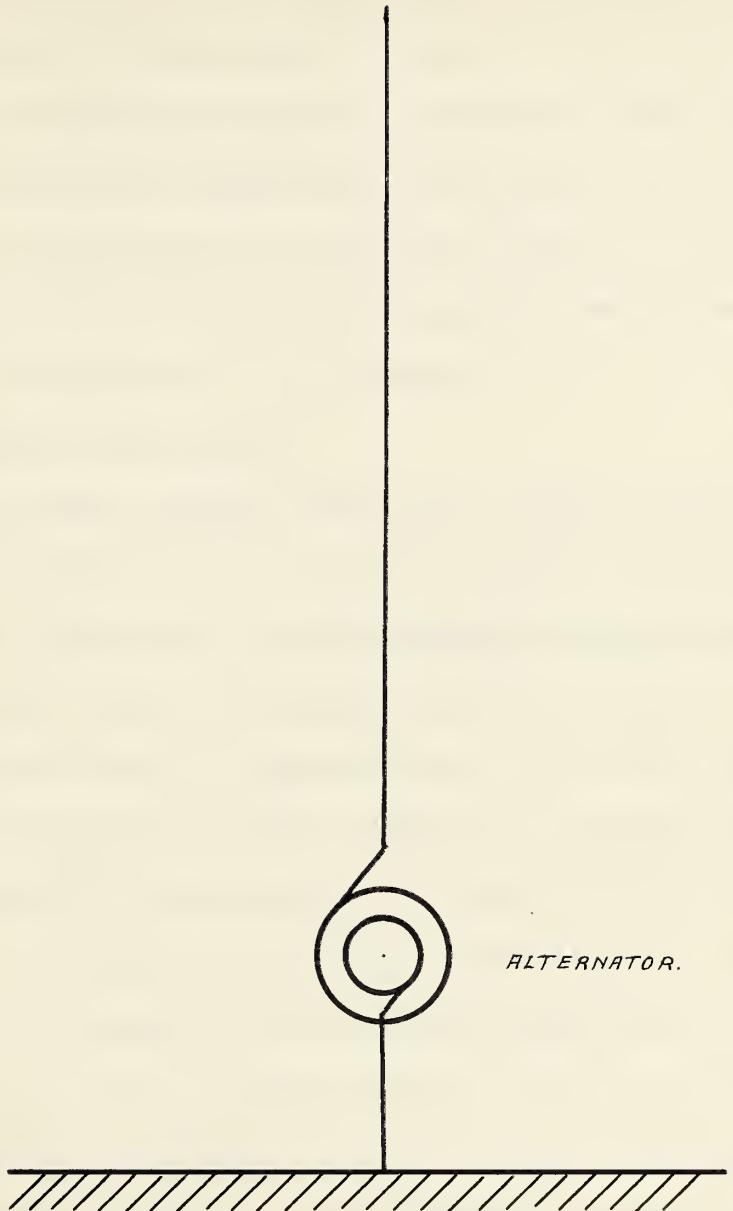


FIG 5.

force. Assuming the absence of magnetic material near the antenna the inductance per unit length should be practically uniform throughout its height.¹ This inductance was measured and the natural wavelength obtained at the same time.

(2). The distributed capacity consists of the capacity between the antenna wires and the counterpoise wires and is in general different for different parts of the antenna. This factor will be referred to again when we deal with the current distribution in an antenna.

(3). Antenna Resistance.

An antenna absorbs power when supplied with high frequency currents from an oscillator. Some of this power is radiated in the form of electromagnetic waves and represents useful power; while the remainder is consumed in various ways and represents a complete loss in so far that it contributes nothing towards radiation. Since the total power expended in an antenna is partly radiated and partly lost we may divide the effective resistance of the antenna into two parts, namely; (1) Radiation Resistance, (2) Loss Resistance. We will discuss each of these in turn.

(1) Radiation Resistance is a fictitious resistance, the value of which is such as will absorb the same power as is

1 This is not strictly true due to the fact that the current in the antenna is not uniform throughout its length. Thus in calculating the inductance of an antenna it is not correct to multiply the inductance per unit length by the length.

radiated for the same current that flows in the antenna. The radiation resistance could be found by dividing the total power radiated by the square of the antenna current. However it is difficult to determine experimentally the total power radiated unless field strength measurements are taken so in this paper the power radiated will be obtained theoretically. This radiation resistance is used as a measure of the ability of an antenna to radiate power; that is an antenna with a high radiation resistance is a good radiator.

(2). Loss Resistance.

The loss resistance is due to a number of losses which we will discuss under the following headings;

Loss due to conductor resistance and eddy currents.

Loss due to dielectric absorption.

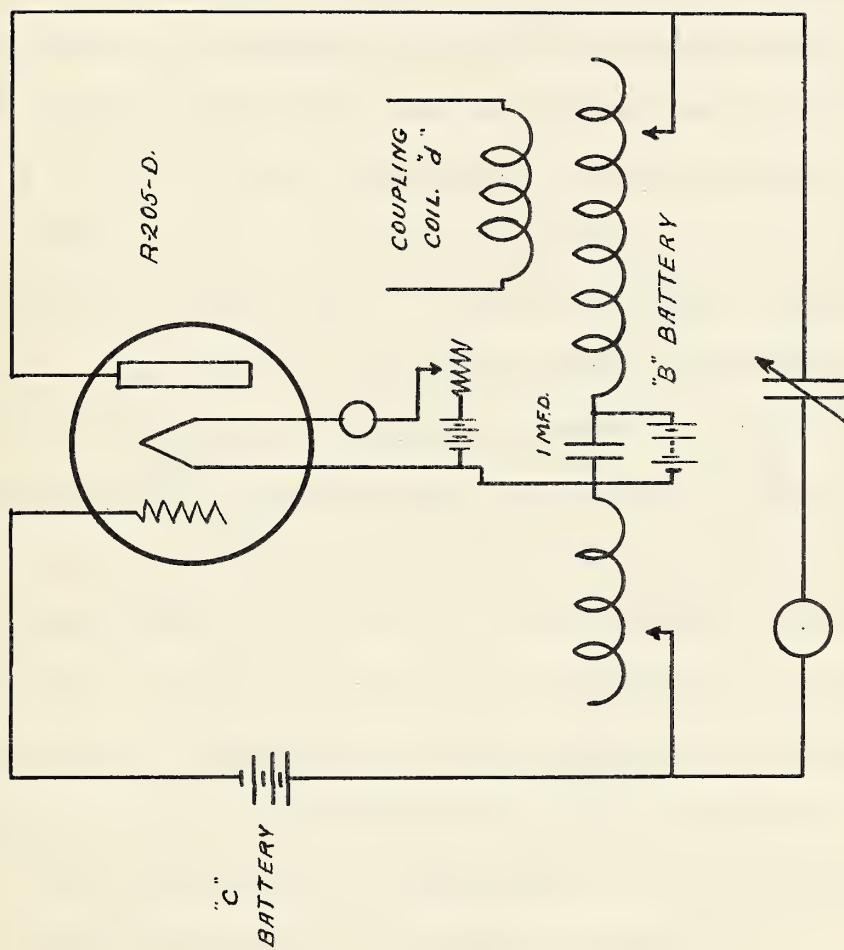
The first of these causes a dissipation of power due to the ohmic resistance of the antenna and counterpoise wires and also the lead-in wires. If the total resistance of the antenna circuit is considered then the resistance of the loading coil must be included in this. Under this heading we also include loss due to eddy currents in the wires and masts. The ohmic resistance will be constant regardless of the frequency but the eddy-current loss will vary as the square of the frequency or inversely as the square of the wavelength. This fact will be noted when the curve is plotted showing the ohmic and eddy-current resistance plotted against wavelength.

The loss due to dielectric absorption is caused by the fact that the antenna is not a perfect condenser. The loss in poor dielectrics is due to a hysteresis phenomenon which takes place in all dielectrics and more especially in dielectrics such as wood, concrete, trees , etc., which may happen to be in the vicinity of the antenna, and hence be acted on by the electrostatic field. This loss resistance is analogous to that due to the magnetic hysteresis in iron, and varies inversely as the frequency or directly as the wavelength. This loss may be reduced to a minimum by keeping the antenna free from unnecessary obstructions such as buildings and trees and also by having the antenna towers some distance from the antenna proper. There is also a small loss due to leakage over insulators but in dry weather this is small. The dielectric loss curve is very nearly a straight line at these high frequencies¹, varying directly with the wavelength. This dielectric loss is usually expressed as a resistance.

Method of Measuring the Antenna Constants.

In order to determine the antenna constants it was necessary to have an oscillator which would be capable of oscillating over a range of from 200 meters to 1000 meters. This was constructed from material on hand, the circuit used being a modified Hartley as shown in figure 6. By means of the variable condenser and the taps on the plate and grid coil the frequency could be varied. The circuit used for

1. Ref. Losses in Dielectrics. Dr. H.J. MacLeod.



HARTLEY OSCILLATOR

FIG. 6.

measuring the antenna constants is shown in figure 7.

A small coil "d" was coupled to the oscillating circuit of the Hartley oscillator, and connected in series with this was a variable inductance "L", the center terminals of a DPDT switch and a thermoammeter. On one side of the switch is connected the antenna and counterpoise, and on the other a precision condenser (General Radio), and a variable non-inductive resistance accurately calibrated. The wavelength at which the oscillator was operating was determined by means of a precision wave-meter (General Radio).

The coupling coil "d" had an inductance of 3.5 microhenrys. The variable inductance "L" was accurately calibrated.

In order to determine the inductance of the antenna the DPDT switch was connected to the antenna and counterpoise 4 turns of the inductance "L"^{were} put in the circuit. The frequency of the oscillator was adjusted till the resonance frequency of the circuit was obtained, that is, the frequency of the oscillator was adjusted till the ammeter reading was a maximum. The wavelength was then read on the wavemeter. This procedure was repeated several times each time adding two or more turns to the inductance "L".

The results obtained are shown in table 1.

The capacity of the antenna and counterpoise for various counterpoise wires was determined by the above procedure except there was no inductance coil "L" used. Two counterpoise wires were used first and the frequency of resonance for these two wires and the antenna was obtained. This was repeated adding one counterpoise wire each time. The results obtained are shown in table 2.

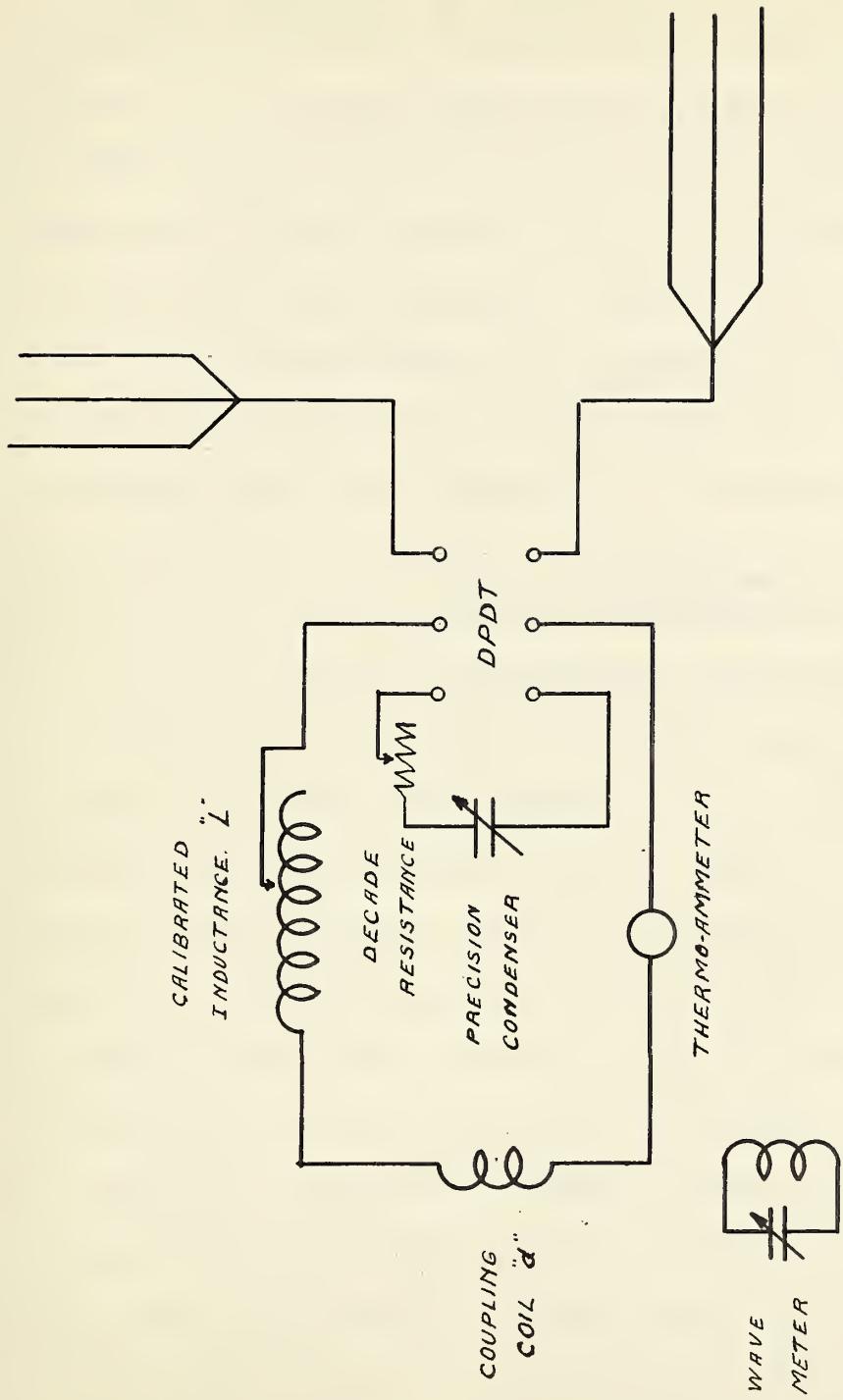


FIG. 7.

The resistance of the antenna was obtained first using six counterpoise wires and then using twelve wires. The method used was a straight substitution method. The frequency of the oscillator was adjusted to some value and the DPDT switch closed on to the antenna side. The variable inductance "L" was adjusted till the circuit was in resonance for that particular frequency. The value of the current as read on the thermo-ammeter was adjusted to some particular value by adjusting the coupling between coil "d" and the oscillator, care being taken that the antenna circuit was kept in resonance. The DPDT switch was now thrown over to the other side and the variable ~~inductance~~^{condenser} adjusted till the circuit was again in resonance. The capacity of the condenser would now be the same as the capacity of the antenna. The variable resistance was now adjusted till the current through the ammeter was the same as before. The value of the resistance would be the resistance of the antenna for that particular frequency. This procedure was repeated for various frequencies, the wavelength being read each time by the wave meter. Necessary precaution was observed to keep the filament current and the plate voltage on the oscillator constant while the readings were being taken. The results obtained are shown in table 3.

The method of obtaining the inductance of the antenna from the results shown in table 1 will now be explained.

The well known equation for resonance frequency, $f = \frac{1}{2\pi\sqrt{LC}}$
 may be changed into $\lambda = \frac{1884}{f} \sqrt{LC}$ using the relation
 that $\lambda = V/f$ where V is the velocity of propagation
 and λ is the wavelength and f the frequency. L and C
 represent the inductance and the capacity of the antenna
 circuit. In the case of the loaded antenna, that is an
 antenna and counterpoise with a loading coil for tuning,
 the term L consists of two terms namely L_0 and L_1 , L_0 being
 the inductance of the antenna alone and L_1 the inductance
 of the loading coil.

$$\begin{aligned}\lambda &= \frac{1884}{f} \sqrt{(L_0 + L_1)C} \\ \lambda^2 &= \frac{1}{f^2} (1884)^2 (L_0 + L_1)C \\ \lambda^2 &= \frac{1884^2}{f^2} \sqrt{L_0 C} + \frac{1884^2}{f^2} \sqrt{L_1 C} \\ \lambda^2 &= \gamma_0^2 + \left(\frac{1884}{f} \sqrt{L_1 C} \right)^2\end{aligned}$$

where γ_0 is the natural wavelength of the antenna and counterpoise. This is the equation of a straight line, the intercept on the horizontal axis being the inductance and the vertical intercept being the natural wavelength λ_0 squared. The capacity of the antenna - counterpoise can now be obtained by substituting λ_0 and L_0 in the formula

$$\lambda_0 = \frac{1884}{f} \sqrt{L_0 C} \quad \text{and solving for } C.$$

Having obtained the inductance of the antenna we can now find the capacity of the antenna - counterpoise as wires were added to the counterpoise from the results shown in table 2.

Table No. 1.

Turns added	"L" added	coil "d"	Total "L" added	Read. W.M?	Wave length	(W.L.) ²
4	5.5	3.5	9.0	248	227	76700
8	13.4	3.5	16.9	296	302	91200
12	23.5	3.5	27.0	355	330	112000
16	35.0	3.5	38.5	427	362	131000
20	47.5	3.5	51.0	501	390	152000
24	60.5	3.5	64.0	578	422	178000

Table No. 2.

No. of Wires	Read. W.M.	Wave length	Cap. of Ant.	Natural W.L.
2	1165	191	.000281	182
3	1360	206	.000326	195
4	1473	214	.000353	206
5	1580	221	.000378	211
6	1696	229	.000404	218
7	1793	236	.000430	225
8	1874	240	.000445	229
9	1955	246	.000466	234
10	2039	251	.000485	238
11	2100	255	.000500	242
12	2169	259	.000516	246

Sample Calculation.

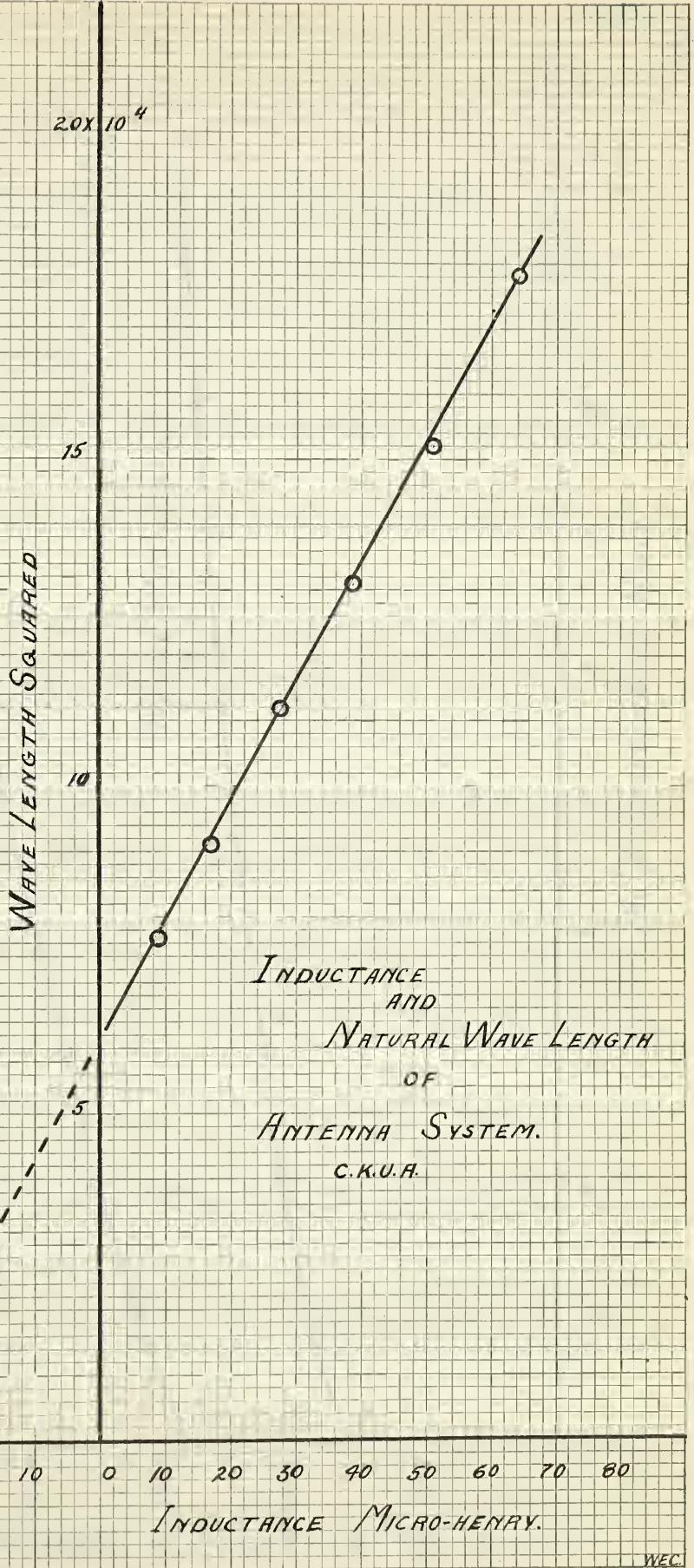
$$\text{Wavelength} \text{ ---- } 1884 \sqrt{L.C.} \quad \text{Inductance of Ant. } 33 \mu\text{H.}$$

From results Table No. 1.

$$\text{"} \text{ ---- } 1884 \sqrt{33 + 3.5 \times C.}$$

$$\text{Capacity} \text{ ---- } \frac{(W.L.)^2}{(1884)^2} \text{ ---- } \frac{36.5}{(1884)^2} \text{ ---- } \frac{191^2}{(1884)^2} \div 36.5 \text{ ---- } .000281 \text{ mfd.}$$

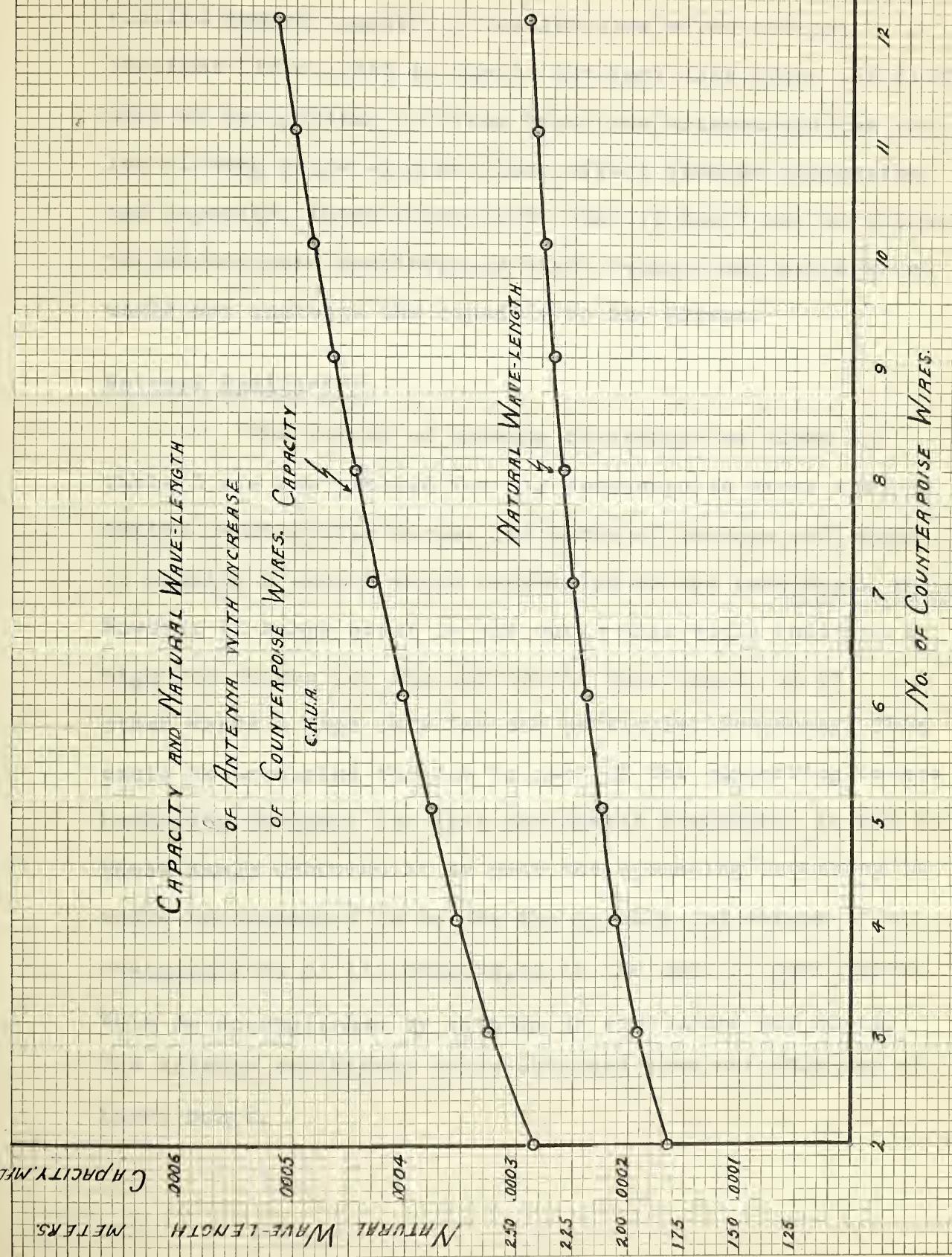
$$\text{Natural wavelength} \text{ ---- } 1884 \sqrt{33 \times .000281} \text{ ---- } 182 \text{ meters.}$$



CAPACITY AND NATURAL WAVE-LENGTH

OF ANTENNA WITH INCREASE

*OF COUNTERPOISE WIRES. CAPACITY
CURVE.*



The curves of capacity and natural wavelength plotted against number of counterpoise wires are not straight lines. This is due to the fact that after the sixth wire we are getting out from below the antenna and the addition of each extra wire has less effect towards increasing the capacity. These curves show that it would not be economical to add any more counterpoise wires because any extra wires would not increase the capacity to any extent.

Antenna Resistance.

The values of antenna resistance as shown in table 3 are now plotted for six counterpoise wires and for twelve counterpoise wires. The curve of antenna resistance is usually a smooth curve decreasing as the wavelength increases ^{up to a certain point}. However if humps occur in the curve this would indicate a high resistance for one particular wavelength, or in other words a high loss for one particular frequency. This could be accounted for due to part of the supporting towers becoming resonant for that particular frequency. If one of these humps occurred at or near the operating frequency it would be necessary to locate the trouble and detune it by changing some of its members, or in the case of some towers this is accomplished by putting up some extra guy wires. The antenna resistance curve obtained does not show any of these humps.

The next problem is to divide the antenna resistance into its components, namely; radiation resistance, ohmic and eddy current resistance, and dielectric resistance. The radiation resistance of the antenna is calculated from a formula for the various wavelengths, and plotted on the same sheet. It can be seen from the calculations that the radiation resistance for wavelengths above 1000 meters is small. The eddy current loss varies inversely as the square of the wave length so at this wavelength the curve representing ohmic and eddy current resistance would be all ohmic resistance and therefore constant. For all other wavelengths above this it would be a straight line. Therefore it is sufficiently accurate to draw in the curve representing dielectric resistance as a straight line parallel to the latter part of the antenna resistance curve and passing through the origin. This curve passes through the origin because at zero wavelength (infinite frequency) the dielectric loss is zero. Now having obtained the curve of radiation resistance and dielectric resistance, the difference between the sum of these and the antenna resistance curve gives the curve of ohmic and eddy current resistance. Before discussing these curves let us consider the derivation of the formula used in calculating the radiation resistance of an antenna.

In order to determine the radiation resistance it is necessary to derive a formula for the total radiation of power from an antenna. Dividing the total power radiated by the current squared we get the radiation resistance. Let us consider briefly the radiation of energy from an antenna. Referring to figure 8 which is the simplest antenna, (a straight vertical wire), we will consider first the distribution of current in this conductor. At the upper end the effective value of the current will be zero since there is no capacity beyond this. The current is a maximum at the base and some of the current from the wire is continually flowing off by the capacity paths to ground so at the top it is zero. The flow of this alternating capacity current through the inductance of the antenna produces an increasing voltage as we proceed towards the end. A similar condition exists in a transmission line, thus we have a current node at the top and a voltage node at the base. Now when we add the flat top as shown in figure 9 the distribution of current is altered, being zero at the ends of the flat portion. As seen from figure 9 the current in the vertical portion is now more nearly constant over its entire length. This feature is desirable in view of the fact that the current which contributes to the vertical component magnetic of the electric field and the horizontal field is that flowing in the vertical part of the antenna.

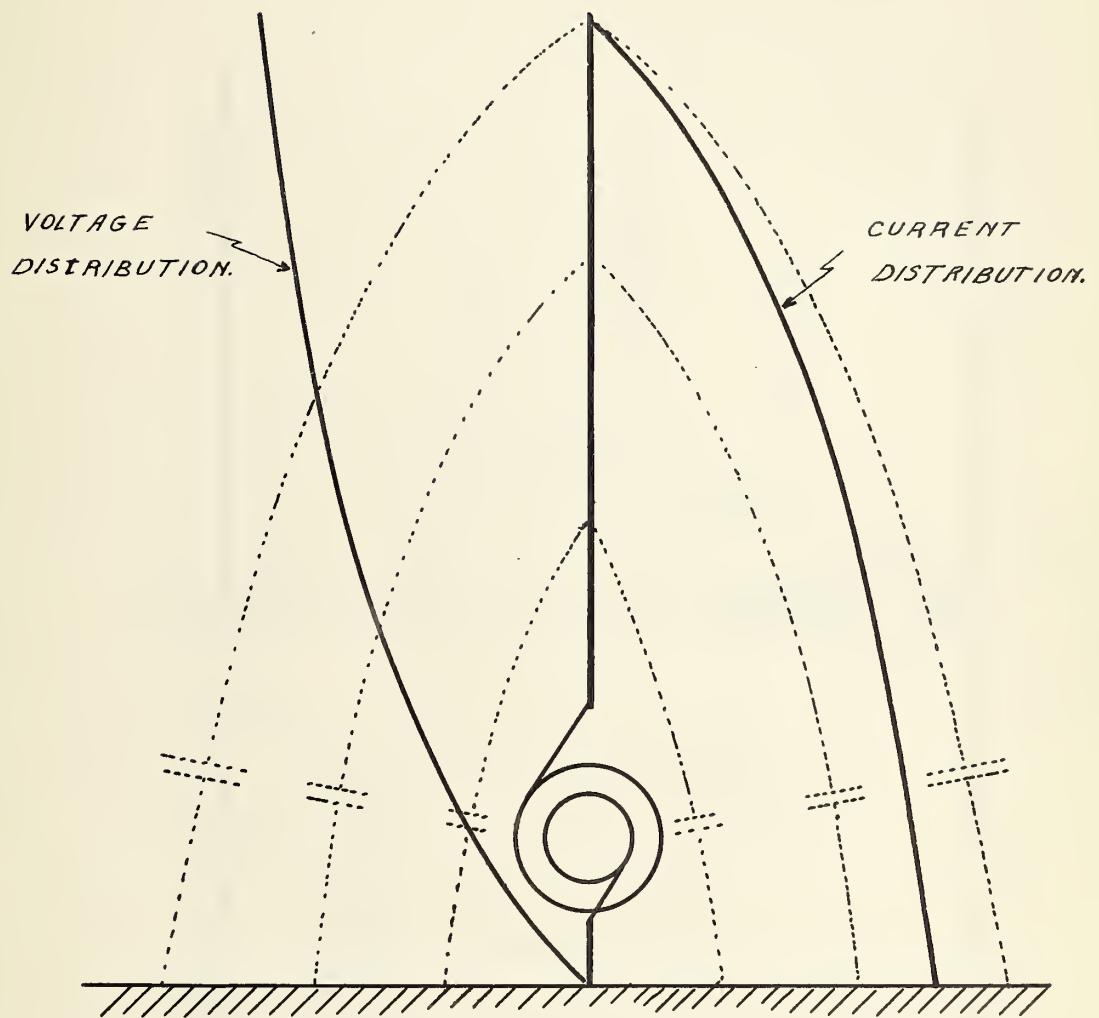


FIG. 8.

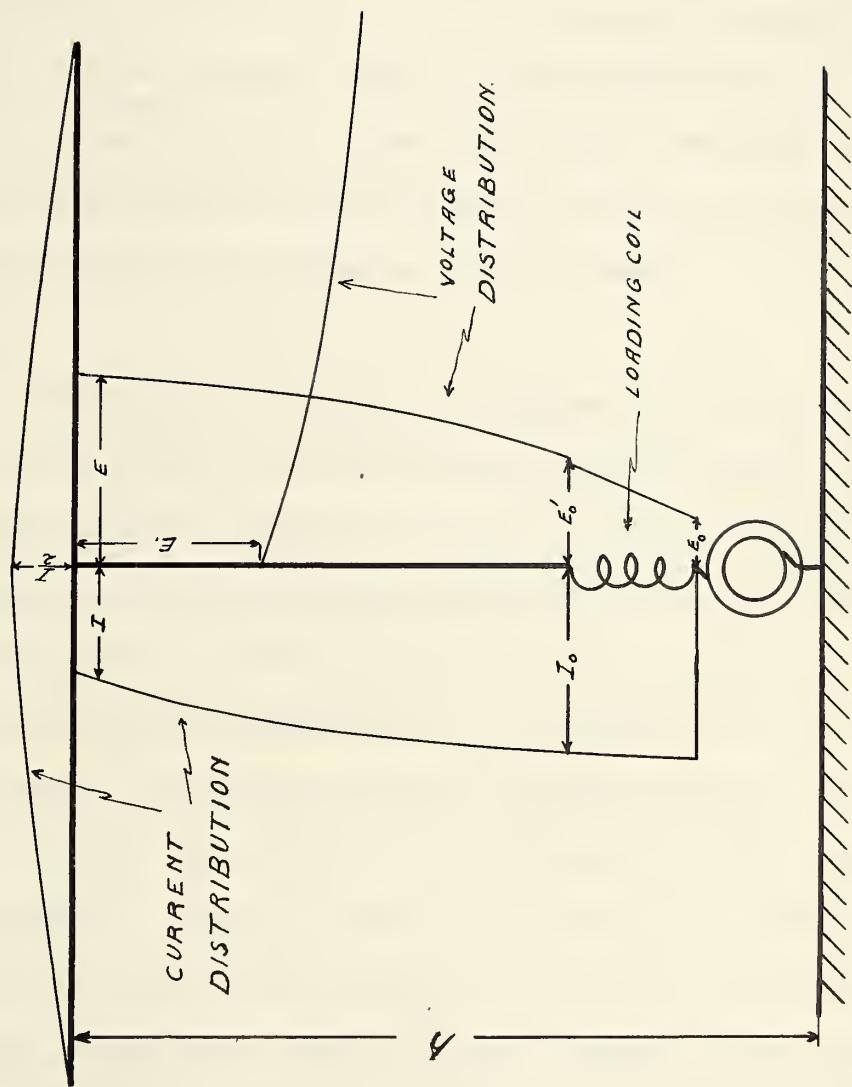
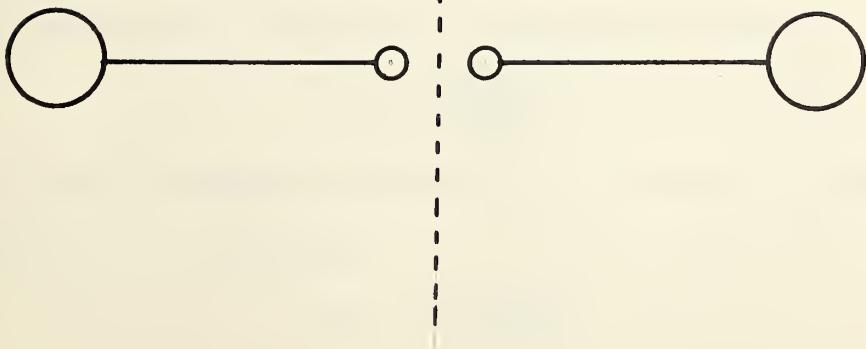


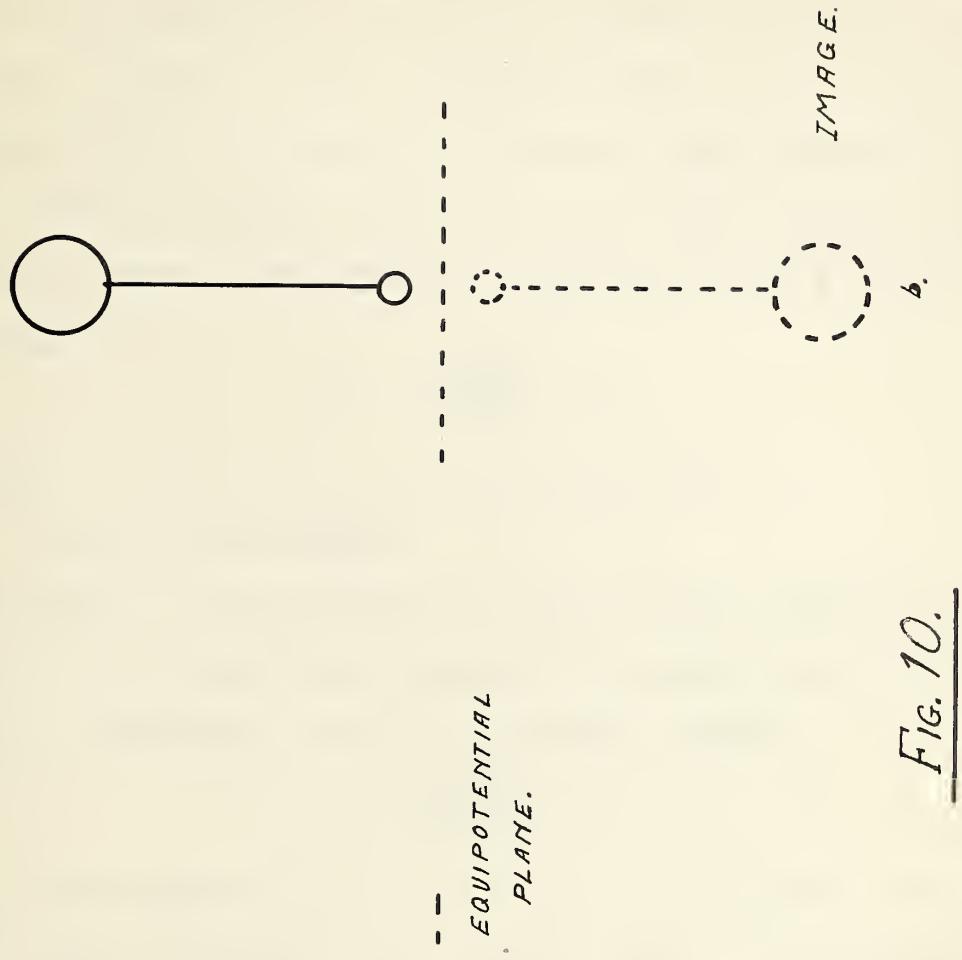
FIG 9

If the effective current were constant throughout the entire height we could obtain the radiation by using the height "h" figure 9 in certain derived formula. As seen from figure 9 however the effective current is not uniform along the vertical portion of the antenna, so an equivalent height "h'" with current equal at all points to that at the base has to be obtained which would give the same radiation. This is called the equivalent height and the current specified is usually that at the base, as that is where it is usually measured.

Professor G.W.Pierce of Harvard in his book entitled "Electric Oscillations and Electric Waves" makes a very thorough and complete analysis of the radiation from an antenna and also the antenna characteristics. He derives equations for the power radiated from an antenna. In this paper only a brief summary will be included. Mr. Pierce in his preliminary treatment derives an equation for the power radiated from an oscillator and in obtaining this considers that the field in space is due to an electric doublet or dipole. In the Hertzian oscillator figure 10 two spheres are charged oppositely until the gap between them breaks down. An oscillation of energy will take place back and forth at a definite frequency and under these conditions energy will be radiated from the system. An equipotential plane may be imagined between the halves of the Hertzian



a.



b.

Fig. 10.

oscillator. Under these conditions this equipotential plane may be replaced by a perfectly conducting surface in which event one half of the oscillator and its image may be used in the solution of the problem. This is similar to a straight vertical wire above the earth's surface. The total power radiated throughout a complete sphere is given by the formula¹

$$P = \frac{80\pi^2 l^2}{\lambda^2} I^2$$

where l is the length of the doublet Fig. 10

λ is the wavelength.

In applying this formula to the radiation from an antenna it must be noted that energy is radiated only in the upper hemisphere, hence the formula becomes,

$$P = \frac{40\pi^2 l^2}{\lambda^2} I^2$$

In this formula "l" is the length of the whole doublet which is equal to $2h$ where "h" is the length of the vertical part of the antenna therefore the power radiated in terms of height and current and wavelength becomes;

$$P = \frac{160\pi^2 h^2}{\lambda^2} I^2$$

Dividing the above equation by the current squared gives the radiation resistance:

$$R = \frac{160\pi^2 h^2}{\lambda^2}$$

1. Electric Oscillations and Electric Waves. by G.W.Pierce
2. High Frequency Alternating Currents. By McIlwain & Brainerd.

Equations similiar to this are given in Bureau of Standards Circular No. 74.

In obtaining the above equations it was assumed that the current is uniform throughout the entire vertical section. This would only be true in the case of ^a large antenna where the horizontal section was long as compared to the vertical section. If this were true the "h" in the equation could be taken as the vertical height. In the case of the antenna under consideration the horizontal part is not very much longer than the vertical part therefore the current is by no means uniform and the equivalent height has to be used in place of the actual height. It was also assumed that the radiation is chiefly from the vertical section.

The vertical height of the antenna was measured by means of a transit and the length of the flat part measured. Using these measurements the equivalent height was calculated as shown in sample calculations. The accuracy of this compares favourably with the accuracy of the other measurements.

Using the above equation the radiation resistance was calculated for a number of wavelengths as shown in table 4. Besides the calculated values there are shown some values of radiation resistance taken from curves page 479, Electric Oscillations and Electric Waves by Pierce. These values compare favourably with the calculated values.

Table No. 3.

Table No. 4.

Wave-length	R _a 6 wires	R _a 12 wire		Wave-length	Rad. Res. cal.	Rad. R. curves.
300	10	8.9		300	7.20	----
400	6.8	5.8		400	4.10	4.20
480	5.4	4.6				
510	5.0	4.3		520	2.50	2.40
575	4.5	3.8		600	1.90	1.80
625	4.3	3.7		700	1.30	1.30
670	4.3	3.6				
705	4.3	3.6		800	1.00	1.00
1000	5.2	4.1		1000	0.70	0.72

Sample Calculations.

Refer to Fig. 9.

Current at the alternator is 9 amps.

Current at the end of the flat portion is zero.

Height --- 82 feet. Length of flat portion ----- 125 feet.

Total length of antenna is 207 feet.

Assume that the current decreases in a straight line relation.

Then current at the top of the vertical section -- $9 \times 125 / 207$ --- 5.4 amps.

Then the effective height(that is the equivalent height over which the current would be constant at 9 amps) is 66 feet.

Radiation resistance from formula is $\frac{160\pi^2 h^2}{\lambda^2}$

$$\text{Rad. Res. } \frac{160\pi^2 66^2}{(300 \times 3.281)^2} \text{ --- 7.20 ohms.}$$

(3.281 ft. in a meter).

Using curves page 479 in Pierce.

a--- 82. b--- 125. y---- b/a+b ---- 0.60

$$\frac{\lambda}{\lambda_0} \text{ ----- } 600/246 \text{ ---- 2.44}$$

246 is the natural wavelength.

Radiation resistance from curves is 1.80 ohms.

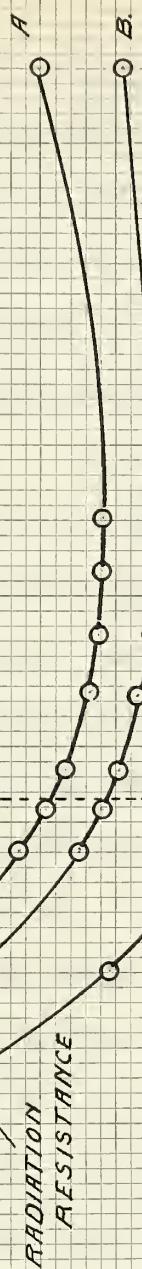
Antenna Resistance Chart

A = WITH SIX COUNTER POISE WIRES
 B = WITH TWELVE COUNTER POISE WIRES

FUNDAMENTAL WAVE LENGTH

WAVE LENGTH

RADIATION
RESISTANCE



DIELECTRIC RESISTANCE ↗

OHMIC & EDDY CURRENT RESISTANCE ↗

100 200 300 400 500 600 700 800 900 1000

WAVE LENGTH IN METERS

Examining the curves it will be observed that the radiation resistance at the operating wavelength (516.9) is over half the total resistance. This is desirable as it shows that the antenna alone has an efficiency of more than 50%. It will also be observed how the radiation resistance increases as the natural wavelength is approached, which shows that it^s more economical to operate as close to the natural wavelength as possible. At a wavelength of 700 meters the efficiency of the antenna alone would have dropped below 40% due to the very low radiation resistance at this wavelength. On the same sheet ~~are~~ is shown the antenna resistance curve for a counterpoise of six wires. At the operating wavelength it will be noticed that the decrease in resistance due to the addition of the extra six wires is .7 ohm. The radiation resistance would be the same for both cases therefore considering the antenna current as 9 amperes there is a saving of 56 watts by the addition of the six wires.

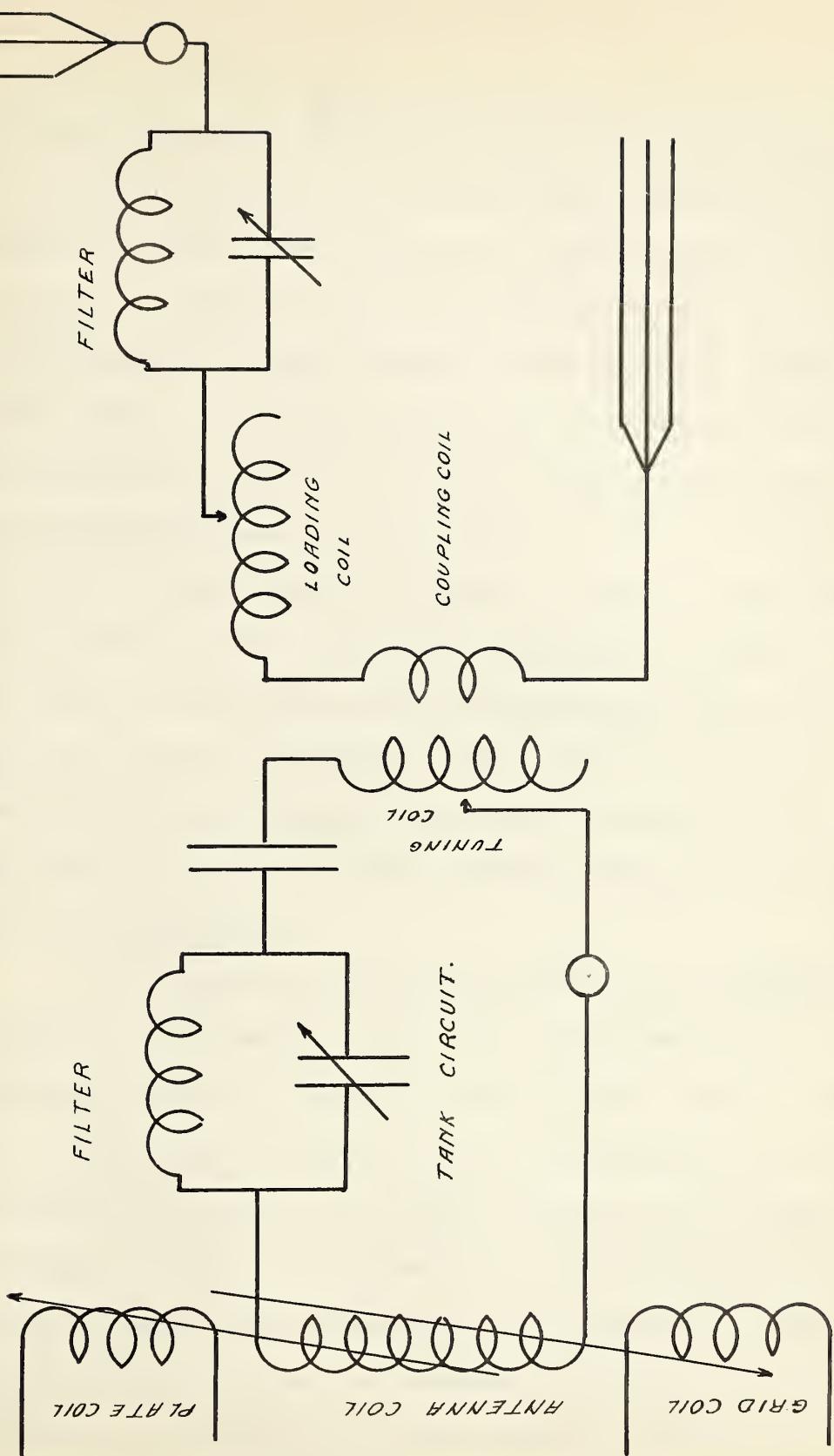
Another saving that was obtained by the addition of the six counterpoise wires is that the loading coil was reduced from 187 microhenrys to 140 microhenrys. This reduced the loss by about 40 watts.

During September 1930 a number of other changes were made and these will be briefly discussed. A filter was installed and the 1600 volt generator was used to supply to plate current for the speech amplifier. This overcame the trouble of maintaining the 500-volt bank of storage batteries that were previously used to supply this plate current.

The circuits were slightly changed and six 250-watt tubes were used in place of four. Three of these were used as oscillators operating in parallel in the same Meissner circuit. The other three were used as modulators. The coupling between the tank circuit and the antenna circuit was changed from inductance coupling using a common coil, to mutual inductance as shown in figure 11.

The circuit that is shown in figure 11 is not a satisfactory one for a transmitter for the following reasons. When the load circuit is coupled to the tuned circuit of the oscillator, (in this case the tank circuit) the maximum output of power is transferred to the load circuit when the transferred resistance of the load is such that the plate resistance and the external plate circuit impedance of the tube are matched. In order to obtain this condition or even approximate this condition the coupling between the tank circuit and the antenna circuit had to be greater than critical. Therefore, as we will see by the theory of coupled

FIG 11



circuits, that there are three frequencies (two stable and one unstable) at which the circuit will oscillate. These correspond to the three inflection points obtained when $x_m^2 > r_a r_b$. A sudden surge of antenna current due perhaps to over modulation would cause the oscillators to swing over to the other stable frequency. Thus it is unsatisfactory to couple the load directly to the oscillating circuit. Another disadvantage to this system is the low efficiency obtained from the tubes. In order to obtain a high efficiency from an oscillating triode it is necessary to operate the tube with a high negative grid bias, that is with either class B or class C operation. This gives a condition of somewhat unstable operation and makes the oscillator hard to start. Thus in order to insure stable operation the efficiency had to be sacrificed..

The above disadvantages led us to changing the transmitter to a master oscillator, power amplifier circuit during the fall of 1931. This is the circuit that is being used at the present time, and is a modification of the principal used by all the large transmitting stations. Referring to figure 12 the master oscillator consists of a R-211-D 50 watt tube operating with a Colpitts circuit. The Colpitts oscillator is somewhat different to the Hartley and Meissner that have been mentioned in the early part of this paper. In place of the grid getting its excitation by

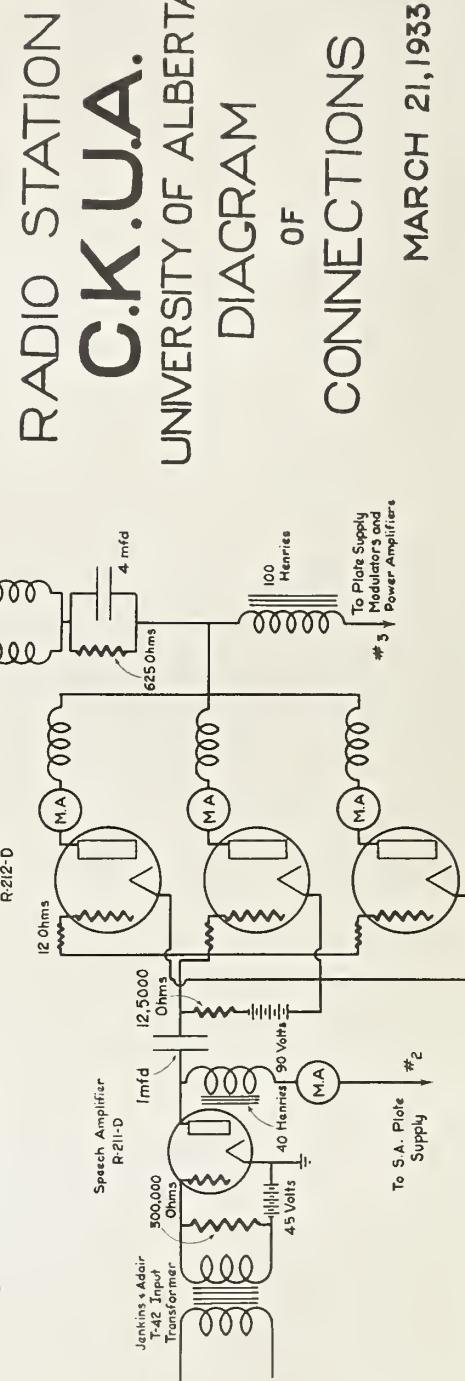
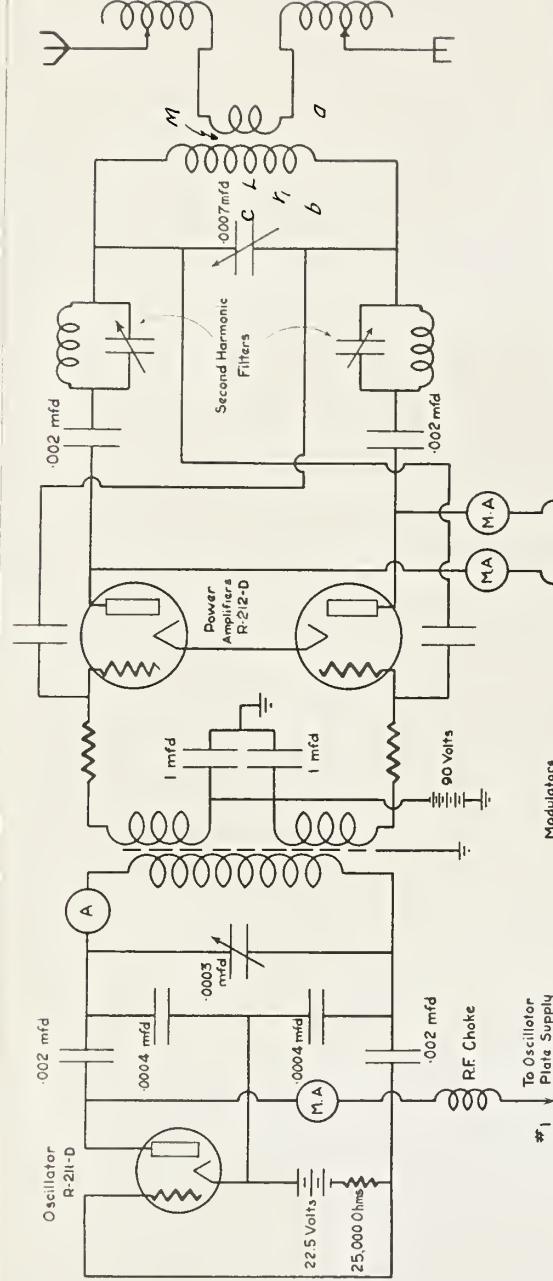
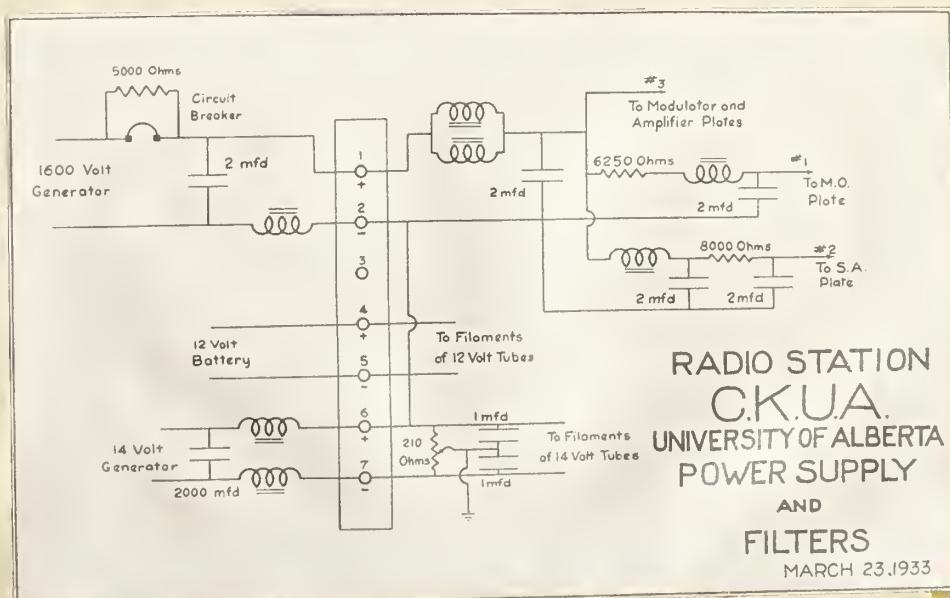


FIG. 12.

Power Supply Circuits for Transmitter.

In the figure below is shown the power supplies for all the tubes. This diagram fits in with figure 12 and the two diagrams have corresponding numbers on the leads.

A few special features to note. The leads from the 14 volt generator come to terminals 6 and 7 and then across the two leads are connected two condensers in series and a 210 ohm resistance. By adjusting the moving contact of the resistance a large amount of hum from the generator is eliminated. This center tap serves as a grid return for the amplifier tubes. Two filter circuits are shown, one in the supply lines to the speech amplifier and one in the supply to the master oscillator. The resistances are shown in the filter circuits which drop the voltage to a suitable value for the smaller tubes. Across the terminals of the 14 volt generator just before the two chokes is a 2000 mfd. condenser. This is an electrolytic type which has very large capacity in a very small size. The purpose of this condenser is to bypass the high frequency ripple caused by the commutator.



induction as it is in the Hartley and Meissner it is obtained by means of a condenser in the grid circuit. By adjusting the size of this condenser the grid voltage is controlled. The oscillating circuit consists of the inductance paralleled by two condenser circuits, one variable and one made up of two condensers in parallel. Grid bias is obtained by means of grid resistance and battery. In the plate circuit an inductance is included to prevent short circuiting the oscillating circuit through the high voltage generator.

The two R-212-D 250 watt tubes are radio frequency amplifiers operating in push-pull with their grids coupled to the master oscillator by means of a special coupling coil. These amplifiers amplify the radio frequency current from the master oscillator, after which it is modulated and then fed to the tank circuit. The one disadvantage to this system is that the modulators have to modulate the radio frequency after it has been amplified and this requires a large amount of tube capacity. A much more efficient system is to modulate the radio frequency current before it is finally amplified, but this system requires one or two stages or buffers between the oscillator and the amplifiers. This could not be satisfactorily obtained in our case as we have only one source of plate current.

The output of any tube operating as an oscillator always contains harmonics which cause interference and

distortion. As I have mentioned previously the second harmonic gave us considerable trouble and one of the advantages of employing radio frequency amplifiers operating in push-pull is/characteristic of eliminating all even harmonics. This is possible however only if the transformers are accurately balanced about their mid points. This characteristic is due to the fact that the excitation voltage to one grid is 180° out of phase with the excitation voltage to the other grid.¹ However, due to the fact that the coupling coils between the master oscillator and the amplifiers are not perfectly balanced, it was necessary to put in two filters for the second harmonic. These are installed in the plate leads to the tank circuit and act very efficiently at these points, because the currents here are comparatively small. Another advantage of operating the amplifiers in push-pull is that they can handle under given conditions of load and voltage considerably more power than twice the power that either tube can handle alone.

There are three methods of operating amplifiers, namely as; A class amplifiers, B class amplifiers, C class amplifiers.

An amplifier is said to operate as class A when the linear portions of its characteristic is utilized. Thus when no signal is applied there will be a definite value of plate current.

1. High Frequency Alternating Currents. by McIlwain & Brainerd

An amplifier is said to operate as class B when it is so biased that with no signal voltage impressed on the grid the plate current is zero. That is the tube is biased to cut off. In this case the power output is roughly proportional to the square of the signal voltage. Considerable grid current may exist for the positive part of the cycle and the input apparatus must be designed to handle this current.

An amplifier is said to operate as class C when the negative grid bias is more than enough to reduce the plate current to zero when there is no signal voltage applied to the grid.

The power dissipated at the plate at any instant in a vacuum tube is equal to the product of the plate voltage and the plate current. Thus in order to obtain ^{high} efficiencies the plate current should only be allowed to flow for part of a cycle. This condition is obtained in the Class B and C amplifiers.

If the grid bias for the radio frequency amplifiers was all supplied by a grid leak, a failure on the part of the master oscillator would cause the grid bias to be reduced to zero and the plate current would reach a very high value. Thus the grid bias is usually supplied by batteries and resistance, the batteries supplying the majority.

Referring to figure 12 it will be noticed that there are neutralizing condensers connected between the grid of one tube and the plate of the other. This is necessary

in order to counteract the internal capacity between the grid and the plate of the tube. These condensers are variable and are adjusted in the following manner. A small thermo-ammeter is connected in one of the leads from the plate to the tank circuit and the master oscillator is operated with no plate voltage on the amplifiers. The two condensers are then adjusted till there is no reading on the thermo-ammeter. This indicates that the capacity of the condensers just neutralize the plate-grid capacity of the tubes.

In order to determine whether the load impedance and the tube impedance are matched and the coefficient of coupling, it will be necessary to briefly summarize the theory of coupled circuits.

COUPLED CIRCUITS.

Two circuits are coupled to one another when they have an impedance in common so that the current in the one causes a voltage in the other. The common impedance may be either pure resistance or pure reactance. Referring to figure 13 let r_a and jx_a be the real and imaginary parts of Z_a where Z_a is the impedance of mesh "a" if mesh "b" were absent. Let r_b and jx_b bear the corresponding relationship to Z_b of mesh "B". Let r_m , x_m and Z_m be the mutual resistance, reactance and impedance. Let E be the voltage applied to mesh "a". The mesh equations are then

$$E - Z_a I_a - Z_m I_b \quad (1)$$

$$0 - Z_b I_b - Z_m I_a \quad (2)$$

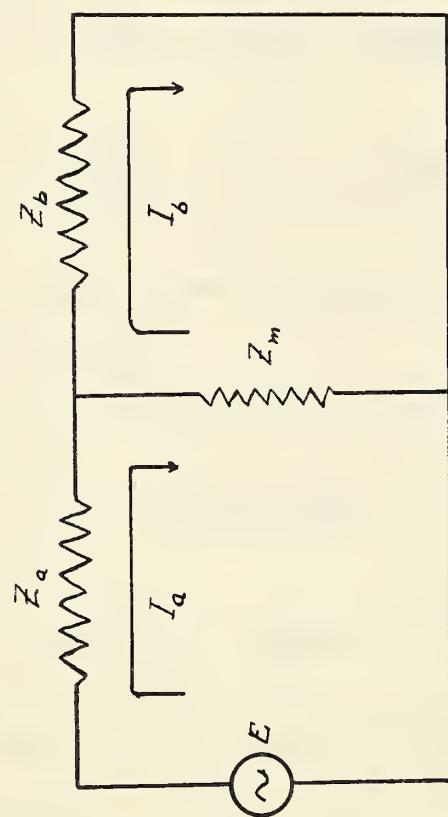


Fig. 13.

Eliminating I_b

$$E - z_a I_a - z_m^2 I_a / z_b \quad (3)$$

or $I_a = \frac{E(z_a - z_m^2/z_b)}{z_b}$ $\underline{\hspace{10em}}$ (4)

Rationalizing the denominator

$$I_a = \frac{E/r_{ab} + jx_{ab}}{z_{ab}} = E/Z_{ab}. \quad (5)$$

where $r_{ab} = r_a + \frac{x_m^2 r_b}{z_b^2} = r_m^2 r_b + 2r_m x_m x_b$ (6)

$$x_{ab} = \frac{x_a + r_m^2 x_b - x_m^2 x_b - 2r_m x_m x_b}{z_b^2} \quad (7)$$

r_{ab} and x_{ab} are called the equivalent primary resistance and reactance respectively.

When reactance coupling is used then equations (6) and (7) become;

$$r_{ab} = r_a + x_m^2 r_b / z_b^2 \quad (8)$$

$$x_{ab} = x_a - x_m^2 x_b / z_b^2 \quad (9)$$

The absolute value of the secondary current is then

$$I_b = \frac{x_m E}{\sqrt{r_a^2 + x_a^2} \sqrt{(r_b + x_m^2 r_a / z_a^2)^2 + (x_b - x_m^2 x_a / z_a^2)^2}} \quad (10)$$

by making $x_b = x_m^2 x_a / z_a^2$ the last term in the denominator may be made to vanish.

$$I_b \text{ max.} = \frac{x_m E \sqrt{r_a^2 + x_a^2}}{r_b(r_a^2 + x_a^2) + x_m^2 r_a} \quad (11)$$

Differentiating equation(11)) to obtain the optimum adjustment for x_a

$$\frac{\partial I_b}{\partial x_a} \max = \frac{[r_b(r_a^2 + x_a^2) + x_m^2 r_a] - \frac{x_m x_a E}{\sqrt{r_a^2 + x_a^2}} - 2x_m x_a r_b E \sqrt{r_a^2 + x_a^2}}{[r_b(r_a^2 + x_a^2) + x_m^2 r_a]^2} \quad (12)$$

The condition for an inflection point is

$$x_a r_b (r_a^2 + x_a^2) - x_m^2 x_a r_a = 0 \quad (13)$$

The solutions of equation (13) to give the alternate adjustments of x_a for inflection points, are

$$x_a = 0 \quad (14)$$

$$x_a = \pm \sqrt{\frac{r_a}{r_b} (x_m^2 - r_a r_b)} \quad (15)$$

It will be noticed that when

$$x_m^2 \text{ is greater than } r_a r_b$$

there are three real values possible for x_a whereas otherwise there is only one real value for x_a .

Referring to figure 14 the three conditions are shown, that is when x_m^2 is greater than, equal to, or less than $r_a r_b$. These conditions are known as greater than critical, critical coupling, and less than critical respectively. By substituting the proper value of x_a in equation (11) the value of secondary current may be obtained for each of the above conditions.

It will be noticed from figure 14 that the maximum current for coupling greater than critical is the same as the maximum current for critical coupling.

The amount of coupling is usually measured by a comparison between the mutual inductance and the self inductance of the two windings. The factor is called the coefficient of coupling and is represented by K.

$$K = \frac{M}{\sqrt{L_p L_s}} \quad \dots 16$$

L_p and L_s are the self inductances of the primary and secondary. M is the mutual inductance.

L_p is equal to $L_a + M$.

L_s is equal to $L_b + M$.

From the above it may be seen that the value of K gives a measure of whether the coupling is greater than, equal to, or less than critical.

In transmitting, K must be comparatively large to obtain sufficient power output, and thus coupling is usually greater than critical. With this condition there are two stable resonant points and if the coupling is only slightly greater than critical these points are close together and the transmitter may operate on either one or the other. This was the trouble we had when the Meissner circuit was used with a tank circuit. However with the master oscillator type of transmitter the frequency of oscillation is fixed by the parameters of the master oscillator and then the degree of coupling is adjusted to give maximum output.

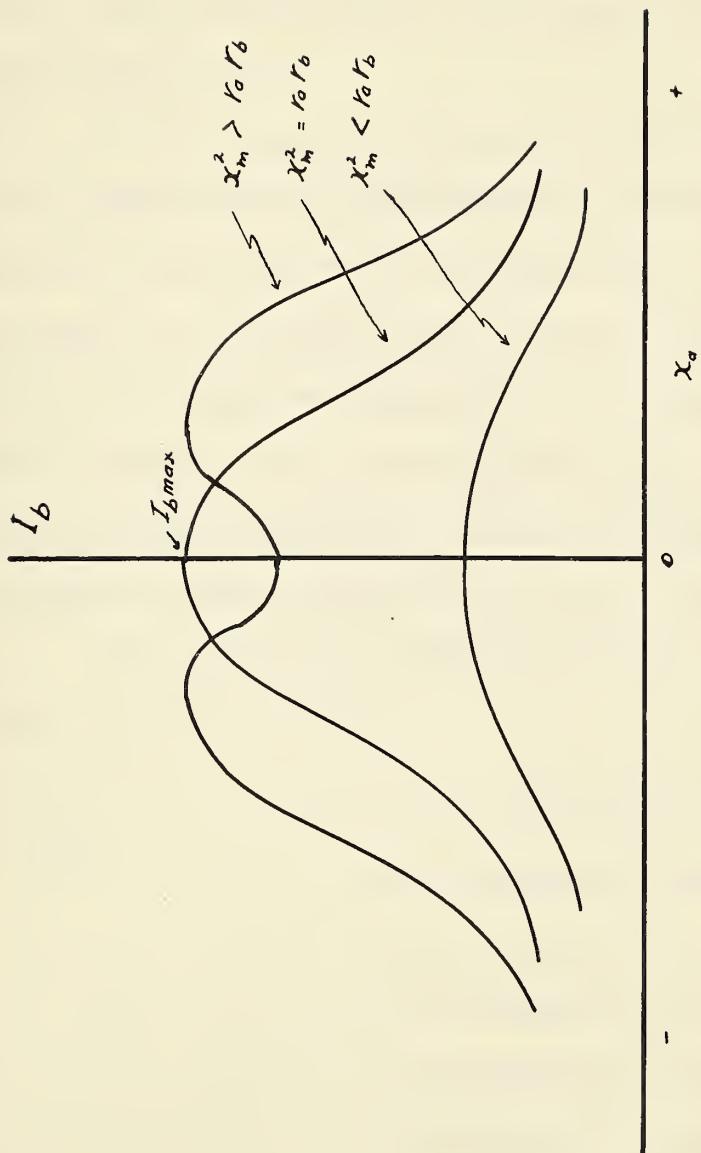


FIG 14.

We will now determine how much the transferred resistance of the antenna and tuning coil is at the plates of the power amplifiers. This should be in the order of the of the total dynamic plate resistance to get maximum output from the amplifiers.

Tabulating the information available;

Antenna resistance at fundamental frequency ----- 4 ohms.

Effective resistance of the tuning coil ----- 1.4 ohms.

Inductance of the tuning coil ----- 144 microhenrys.

Capacity of antenna-counterpoise ----- .00052 mfd.

Mutual inductance of coupling coil ----- 2.25 microhenrys.

Capacity of tank condenser ----- .0007 mfd.

Inductance of tank tuning coil ----- 107 microhenrys.

The following formulae will be used in the calculations. Refer to Fig 12.

$r = \frac{L}{r_1 C}$ r --- is the equivalent series resistance
of a parallel circuit at resonance.

L --- is inductance of coil.

r_1 --- is resistance of coil.

C --- is capacity of condenser. Resistance
of condenser is neglected.

$$r_{ab} = r_a + \frac{x_m^2 r_b^2}{Z_b^2} \quad \text{Equation 8 page 27.}$$

$$K = \frac{M}{\sqrt{L_p L_s}} \quad \text{Equation 16 page 29.}$$

$$\text{Efficiency} = \frac{M^2 W^2}{M^2 W^2 + r_a r_b}$$

This formula for the efficiency is taken from Electric Oscillations and Electric Waves by Pierce Equation 72, page 173

$$K = \frac{2.25}{146.25 \times 10^9.25} = 1.78\%$$

$$r_{ab} = \frac{5.4 + \frac{(2\pi f M)^2 \times 10^6}{10^7}}{5.4 + \frac{6.71 \times 10^7}{10^7}} = 11.66 \text{ ohms}$$

$$r \text{ (equivalent series resistance of parallel circuit)} \\ = \frac{10^7}{11.66 \times 0.0007} = 13,000 \text{ ohms.}$$

The total plate impedance is 4000 ohms, but this increases to about 8000 ohms when the amplifiers are operated as B class amplifiers. The transferred resistance as obtained above is a little high for the tubes that are being used at the present time. This transferred resistance can easily be lowered by slightly changing L and C of the tank circuit. Let us assume that L of tank circuit is 90 microhenrys. Then C of tank circuit is .000835 mfd.

r_{ab} will now be 12.85 ohms and the total transferred resistance will be 8400 ohms. This small change makes a very small change in K which now comes out to be 1.94%

$$\text{Efficiency} = \frac{(2\pi f)^2 M^2}{(2\pi f)^2 M^2 + r_a r_b} = 92\%$$

Using the assumed values the efficiency obtained is 93.2%

This gives the efficiency of transfer from the tank circuit to the antenna circuit and holds as $\log^{\frac{1}{n}}$ as the tank circuit is tuned to resonance.

In this paper I have briefly outlined the major changes that have been made to the transmitting equipment of the University of Alberta Radio Station since it was first installed. In order for the transmitting equipment to be more or less up to date periodic changes have to be made due to the fact that every few months new and more efficient methods of broadcasting are coming into use. Due to the financial conditions under which the Radio Station operates the above process of evolution has had to be more or less gradual.

In conclusion the author wishes to thank Dr. H. J. MacLeod who directed and assisted with all the alterations mentioned in this paper; also Mr. J. W. Porteous for the photographs contained herein.



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